J. Perinat. Med.
14 (1986) 399

The fetal electrocardiogram: current clinical developments in Nottingham

Henry G. Murray

Department of Obstetrics and Gynecology, University Hospital, Queen's Medical Center, Nottingham, U.K.

1 Introduction

Over the past seven months, in Nottingham, an enhanced averaging technique using a DEC minicomputer, as described by KIRK*, has been used to analyze the fetal electrocardiogram (FECG) from 155 women in labor. These are the first cases in what is to be a two-year prospective study to correlate the FECG as recorded by this method with fetal well-being as defined biochemically and by neo-natal examination.

Patients entering the study were chosen according to their availability. As it is only possible at present to monitor a single labor 'on-line' each day, the patient in the labor ward whose pregnancy was adjudged to be at greatest risk for intrapartum problems was selected for study. As the FECG recording required no procedures not normally employed in labor, written consent by the patient was not required.

Of the women studied, therefore, 70% had labor surgically induced either at or before term for problems of hypertension, growth retardation, diabetes, twin pregnancy or post-term, that is up to 42 weeks gestation, for those pregnancies diagnosed as being post-dates. This last group provided in large part the labors that were usually uncomplicated. 30% of women monitored entered labor spontaneously but were studied either because of a lack of other material being available, or due to some abnormality having occurred in labor e.g. delay in progress, meconium staining of the liquor, abnormal CTG pattern. There is, therefore, an unashamed bias towards the selection of high risk pregnancies in this study.

Recording of the FECG was via a commercially available Copeland scalp electrode in 153 cases, and a Rocket spiral electrode in 2 cases. Recording was always continuous. Lengths of labor ranged from 0.5 hours to 15.5 hours, with a mean duration of just over 7 hours. The clinical course of the labors was controlled by

Curriculum vitae

HENRY MURRAY *studied medicine at Otago University, New Zealand and graduated MB.Ch.B. with distinction, and B.Med.Sci., after studying the electrophysiology of the cerebral cortex. At present he is specializing in obstetrics and gynecology and is fulfilling the elective component of the Membership requirements as a Research Fellow in the Department of Obstetrics and Gynecology, Nottingham.*

* KIRK, DL: Advanced fetal monitoring systems. J Perinat Med, this issue pp 391

the routine on call labor ward staff who used cardiotocographic (CTG) records and fetal scalp (or buttock) capillary blood sampling to check fetal condition. ECG changes were not used to influence the management of labor. Following delivery the umbilical cord was clamped immediately and anaerobic samples of arterial and venous blood were aspirated into preheparinized syringes for full bloods gas analysis. Venous blood was also taken for estimations of hemoglobin, potassium, whole blood lactate, adrenaline and noradrenaline levels.

Of the 155 pregnancies monitored, 137 (88%) were presenting by the vertex, 15 by the breech, and 3 were found to have a compound presentation following induction.

Of the vertex presentations: 15 (9.7%) required LUSCS; 8 for fetal distress as defined by CTG changes accompanied by a fetal scalp blood pH of less then 7.23; 6 for cephalo-pelvic disproportion; and 1 for continuous ante-partum hemorrhage.

Thirty four percent (34%) of vertex presentations required delivery assistance in the form of rotational forceps in 10 cases, ventouse delivery in 4 cases, and non-rotational forceps in 23 cases. Five of the 15 breech presentations were delivered by LUSCS, 4 for delay in labor progress, and 1 for fetal distress.

In 16 patients, results were in some way unsatisfactory. No arterial cord blood sample was obtained in 7 patients, and in a further 3, the amount of blood obtained was insufficient for a base excess estimation. Three recordings had episodes where the signal to noise ratio was less than 6 and therefore these labors were not suitable to ECG analysis. Three labors ended with cord entangelemts and severe shoulder dystocia, and blood gas analysis was therefore of limited value for our study.

2 Results

2.1 ECG morphology

P wave: A P wave was found to be present in all cases recorded. In three case however, the wave became inverted for periods of up to 3

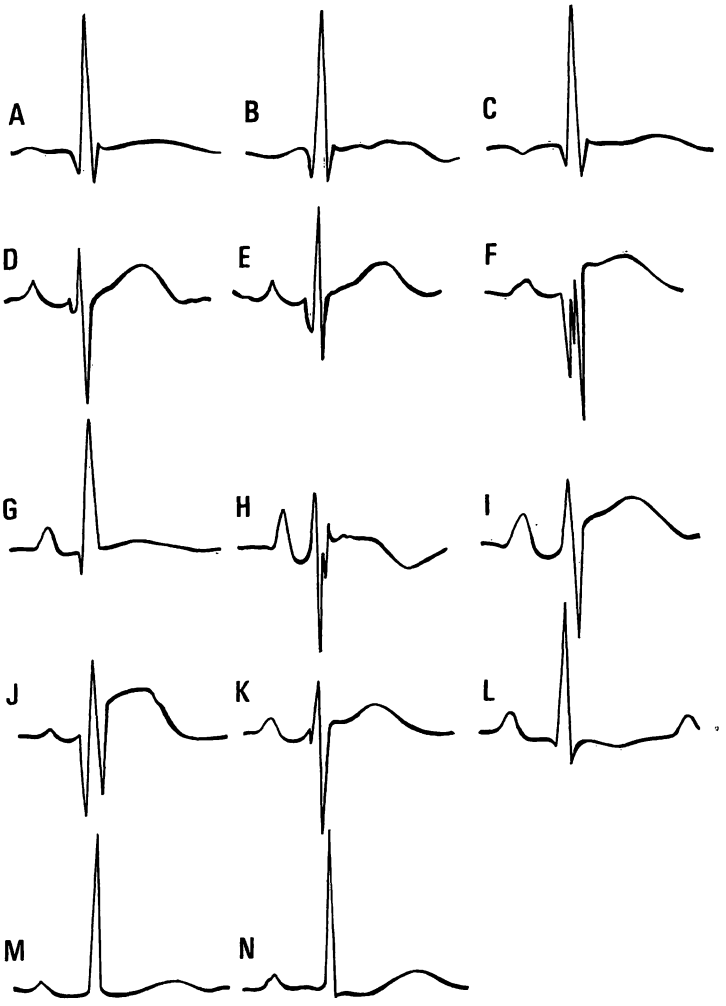

Figure 1. FECG recordings.
A, B, C: Three complexes recorded from the same patient over 10 minutes showing upright P wave (A), absent P wave (B), and inverted P wave (C), with no QRS, ST, or T wave changes.
D, E: ECG complexes recorded from one patient with the scalp electrode placed over the fetal sinciput (D), compared with the scalp electrode placed over the fetal occiput (E).
F: Recording of FECG when the scalp electrode was accidentally placed on the fetal temple.
G, H: The FECG complexes recorded from a single fetus. G shows the ECG complex recorded 30 minutes before that in H. No change in scalp electrode position, fetal acid-base status or signal strength were noted to explain the change in complex configuration.
I, J: FECG complexes recorded from two different fetuses showing mild (I) and marked (J) ST segment elevation in spite of normal fetal pH levels.
K: FECG complex from a fetus with pH 7.07. ST segment shows no marked alteration to suggest the presence of fetal acidosis.
L: FECG complex from a normal fetus showing T wave inversion.
M, N: FECG recordings from the same fetus showing: M the complex recorded during a period when fetal acidosis was not suspected, and N the complex recorded with definite evidence of fetal acidosis.

minutes (see figure 1 A, B, C). As the wave was inverting it was found to disappear momentarily. There was no suggestion in any case of idioventricular or nodal rhythms. Periods of inversion of the P wave did not correspond to contractions, or fetal acidosis or hypoxia.

On numerous occasions, the P wave was seen to be notched with up to 3 msec separating the two components of the wave. Such a change could be a temporary or permanent feature of a recorded ECG and not correlate with any specific fetal condition.

Tall P waves were also frequently encountered, again with no diagnostic significance.

PR segment: Commonly this segment became depressed below the isoelectric line (see figure 1 H), especially in cases where there was a large amplitude Q or S wave. The depression uncommonly lasted throughout the PR segment but usually the potential rose back towards the isoelectric line to be interrupted by the QRS complex. The rise in potential was then seen to continue into the ST interval. These potentials probably correspond to the T_a (T_P) wave of atrial repolarization. They did not correspond to any specific acid-base status of the fetus.

QRS: A large variety of QRS complex shapes were compatible with a normal fetal outcome. In part, the shape was determined by siting of the scalp electrode, as shown in figure 1 D, E, F. In the first of these figures the scalp electrode had initially been sited over the sinciput (figure 1 D). As labor progressed the fetal head flexed taking the electrode further into the genital tract as it did so. Resiting the electrode on the occiput resulted in the complex as shown in figure 1 E. Figure 1 F is an illustration of the complex obtained when the scalp electrode was mistakenly placed on the fetal temple.

The recorded QRS complex was also noted to change during labor in a small percentage of cases without the scalp electrode being resited. Figure 1 G & H illustrates one gross example of this. Figure 1 G was the complex recorded from a single fetus during labor. Over a period of 30 minutes the recorded complex changed to be that as shown at figure 1 H. It will be noted that the PR segment had become depressed, the QRS complex had become grossly altered and the T wave had become inverted. A scalp blood sample taken at this stage was compatible with a healthy fetus pH 7.39, and signal and noise levels were as for figure 1 G. Labor became established after a further hour following which time T wave reverted to the upright position. The ECG complex subsequently remained unaltered until delivery of a normal healthy baby (umbilical artery pH 7.33) some 2 hours later.

In 3 cases the QRS complex was seen to bifurcate completely with a single P wave being followed by duplex QRS complexes and a single T wave. In two of the cases bifurcation was episodic but in the 3rd case it was a permanent feature during labor that was not recorded in the neonatal period. Bifurcation of the QRS complex was found to be compatible with normal fetal acid-base balance and normal neonatal cardiovascular examination. In summary, no QRS complex configuration was found to be indicative of fetal condition. More specifically, the presence of Q waves, notching of the R wave or presence of an S wave was seen across a full range of fetal conditions.

ST segment and T wave: The absolute position of the ST segment above or below the isoelectric line, or height of the T wave whether upright or inverted did not correlate with any particular fetal condition, and did not appear to directly correlate with myocardial hypoxia as in the adult. Figure 1 I & J show respectively mild and marked ST segment elevation in two labors not affected by acidosis (umbilical artery pH > 7.30). Figure 1 K, however, shows an ECG complex from a fetus affected by hypoxia secondary to severe umbilical cord occlusions. The isoelectric ST segment gives no indication of fetal pH of 7.07. Some indication was noted, however, that an alteration of the ST segment position with respect to the isoelectric line during labor could be indicative of fetal condition (see below).

An example of T wave inversion occurring with a normal pH value of 7.35 is shown in figure 1 L.

2.2 Time intervals

P wave duration: P wave duration, as measured just prior to delivery, was found to be correlated negatively with umbilical vein noradrenaline levels in the fetus, $r = -0.4$ $p < 0.03$.

P-R interval: The P-R interval, as measured just prior to delivery, was found to be correlated negatively with umbilical vein adrenaline levels $r = -0.65$ $p < 0.001$. Secondly, P-R interval as a measure of atrioventricular node conduction time, is known to be sensitive to vagal tone.

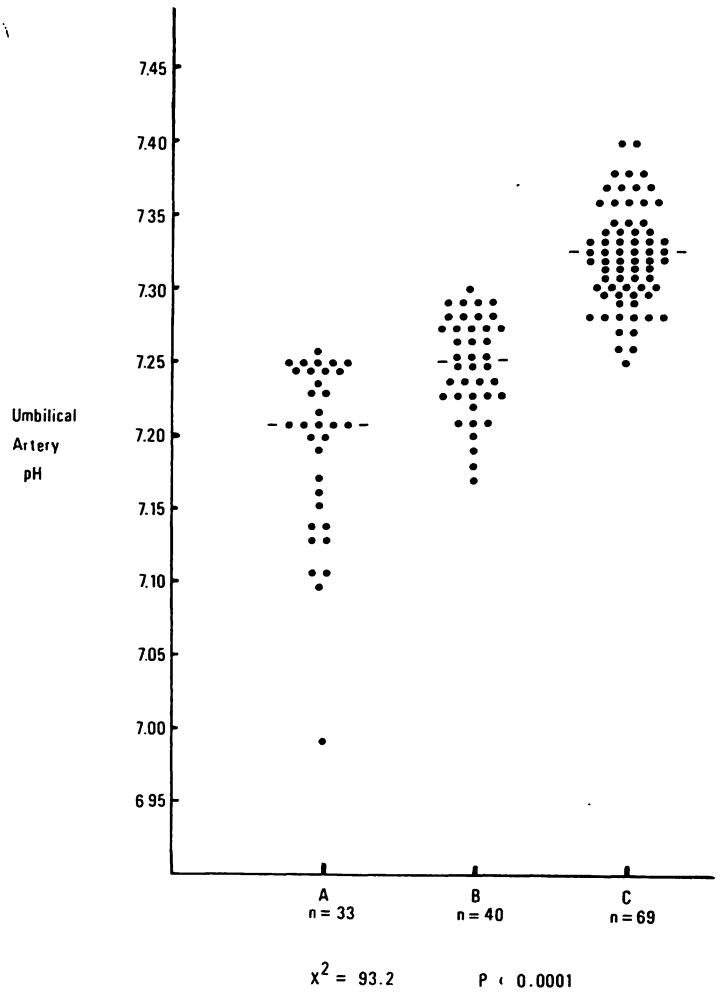

Figure 2. Changes within the FECG complex correlated against umbilical artery pH at delivery. Population A includes all cases with a negative correlation between the PR interval and the RR interval, associated with a change in ST segment level of > 5% of the R wave height. Population B includes those cases with a negative correlation between the PR interval and RR interval alone. Population C includes those cases with a normal positive PR–RR interval correlation. The difference between the pH values for each group is highly significant: $X^2 = 93.2$, $p < 0.0001$.

Decelerations on the basis of increased parasympathetic activity were therefore easily diagnosed through increased P-R intervals. Thirdly, it was noted that in the healthy fetus the P-R interval correlated with R-R interval (r up to 0.95). Fetuses which gave normal positive correlation ($r > 0.3$) all had umbilical artery pH values greater than 7.24 at delivery ($n = 69$) (see figure 2). The close relationship between the P-R interval and the R-R interval appeared to alter as the fetal pH and base excess, measured either by scalp sampling or by cord sampling, began to drop. A negative correlation whereby the R-R interval was seen to increase despite the shortened P-R interval, indicated umbilical pH artery values of 7.17–7.29, mean 7.25 ($n = 40$), and these values were significantly different from the fetuses with positively correlated P-R–R-R intervals, using the Kruskal-Wallis correlation by ranks: $- X^2 = 53.1$ $p < 0.0005$ (see figure 2). A further population of fetuses is identifiable by investigation of the ST interval. It was apparent that when fetal condition deteriorated in the face of advancing labor, the ST interval apparently shifted from its normal stable position to either rise or fall with respect to the isoelectric line. An alteration of the ST interval position by greater than 5% of the QRS height in association with a negative P-R–R-R correlation indicated an umbilical artery pH in the range of 6.99–7.26 ($n = 33$). The pH values for these fetuses were significantly different from those with a positive P-R–R-R correlation but no ST interval change ($X^2 = 20.5$ $p < 0.001$) (see figure 2). The difference between the 3 populations with respect to the pH of the umbilical arterial blood at delivery was found by Kruskal-Wallis correlation by ranks to be significantly different: $x^2 = 93.2$, $p < 0.0001$.

The fact that ST segment alterations could be very subtle is illustrated in figure 1 M & N. Figure 1 M shows the ECG complex recorded in early labor in a singleton pregnancy. No evidence of fetal distress was noted by cardiotocographic record and the liquor draining was clear. Six hours later, in the presence of meconium stained liquor and hypoxic heart rate decelerations on the cardiotocograph, a fetal scalp

blood sample revealed a fetal pH of 7.14 (base excess −7 mmol/L). The ECG recorded at this stage is shown in figure 1 N where little change in the complex is seen apart from a mild ST interval depression. Fetal status at delivery by cesarean section was confirmed by umbilical artery sampling which showed pH 7.07, base excess −12 mmol/L.

QRS duration: The QRS duration measured in labor for each fetus was not found to correlate with fetal condition, or fetal weight $-r = 0.11$ $p < 0.1$. The QRS duration was seen to vary in labor by up to 25% of its mean value. Progressive lengthening or shortening of this duration did not correlate with fetal condition.

R-T, Q-T and Q-T_c intervals: These intervals were found to correlate strongly with R-R interval. Comparisons of these values with fetal acid-base parameters are still being calculated, but preliminary work does not show any strong associations.

T wave parameters as yet require further work to determine any significance with respect to fetal condition.

3 Discussion

Although this work is as yet incomplete, it is clear that although the fetal electrocardiogram can now be isolated in labor, the determination of fetal reserve and status by this method is not immediately evident. Largely this is because it has been necessary to collect data from a large number of cases in order to determine the range of fetal ECG complexes which are compatible both with a normal fetus, and a fetus with proven intrapartum hypoxia. What has been clearly shown is that on-line analysis of the fetal ECG is possible in labor. Such analysis has shown that there is a large variation in the shape of complexes from the normal fetus. Interpretation of the different shapes is hampered greatly by the fact that only a uniplanar recording of the fetal cardiac potential vector is possible at present. Thus comparisons of the morphologies of complexes recorded from different fetuses, and from different electrode sites in the same fetus are hazardous.

It is certain however that the measurement of time intervals within the ECG complexes is the most objective form of analysis. With this in mind our investigations have shown that close measurement of the P-R interval reveals clear information about fetal autonomic nervous activity. For the first time it is possible to clearly differentiate between fetal heart rate decelerations which may be autonomically mediated i. e. those associated with an increased P-R interval length, and those which are metabolically mediated i. e. secondary to fetal hypoxia. There also appears to be emerging some trends which suggest that as fetal condition deteriorates in labor, the R-R interval dissociates from what is normally a close positive correlation with the P-R interval. Such a change in correlation appears to suggest that as the myocardium becomes metabolically impaired and is unable to maintain an adequate heart rate thus increasing the R-R interval, there is an increase in sympathetic tone as indicated by shortened P-R interval. So long as the ventricle is unable to respond to this increased sympathetic tone, there remains a negative correlation between the P-R and the R-R intervals. Further, as acidity of the fetal blood increases still further an alteration in the ST interval of the ECG appears to occur. The direction of the movement of the ST interval with respect to the isoelectric line in response to this worsening metabolic status was seen to be either elevation or depression. Possibly the inconsistency of movement is a product of the relationship between the plane in which the ECG is recorded and the cardiac vector, rather than a result of a varying cardiac pathology in response to the hypoxia.

As yet there does not appear to be any single ECG change from the fetus which unequivocally suggests the need for delivery of the baby. It is possible however that multivariant analysis of the ECG waveforms, eg, correlation of P-R interval with R-R interval, coupled with magnitude of ST segment movement from the isoelectric line over a given time period, may bring us closer to determining a reproducible objective indicator of fetal status. Further work is continuing to see whether such multivariant analysis will be of benefit.

Summary

The fetal electrocardiogram (FECG) has been recorded from 155 women in labor using a fetal scalp electrode and a minicomputerized enhanced averaging technique. Fetal hypoxia, acidosis, and stress have been diagnosed by analysis of blood from the fetal scalp, and post delivery from full gas analysis from blood taken from the umbilical artery and vein. Umbilical venous levels of serum lactate, adrenaline, noradrenaline, potassium and hemoglobin were also determined.

A P wave was seen to be present in all cases recorded. The P-R interval correlated both with fetal autonomic nervous activity, and with the R-R interval of the healthy fetus. The P-R – R-R interval correlation altered with increasing fetal acidosis. QRS complex changes were varied and not usually related to fetal condition. ST segment changes occurred with increasing fetal acidosis. T wave analysis although incomplete, has shown no obvious correlation with fetal condition.

Keywords: Electrocardiogram, fetal acidosis, fetal monitoring.

Zusammenfassung

Das fetale EKG: zum Stand der klinischen Entwicklungen in Nottingham

Bei 155 Frauen unter Geburt wurde unter Benutzung einer fetalen Skalpelektrode und von minicomputergestützten, mittelwertbildenden Algorithmen ein fetales EKG abgeleitet. Die Fetalblutanalyse wurde zur Diagnose einer Hypoxie, Azidose oder eines anderen fetalen Stresszustandes eingesetzt; post partum wurde eine vollständige Blutgasanalyse aus der Nabelarterie bzw. -vene durchgeführt. Ebenso wurden aus der Nabelvene der Laktat-, Adrenalin-, Noradrenalin- und K^+-Spiegel im Serum sowie der Hb bestimmt.

In allen Aufzeichnungen war eine P-Welle gut darstellbar. Bei gesunden Feten korrelierte das P-R-Intervall sowohl mit der Aktivität fetaler autonomer Zentren wie mit dem R-R-Intervall. Mit zunehmender fetaler Azidose änderte sich diese Korrelation zwischen P-R- und R-R-Intervall. Veränderungen der QRS-Komplexe waren unterschiedlich und korrelierten gewöhnlich nicht mit dem fetalen Zustand. ST-Streckenveränderungen nahmen mit steigender Azidose zu. Die Analyse der T-Welle gelang noch nicht vollständig; jedoch scheinen Veränderungen der T-Welle nicht mit Veränderungen des fetalen Zustandes zu korrelieren.

Schlüsselwörter: Elektrokardiogramm, fetale Azidose, fetale Überwachung.

Résumé

F. E. C. G.: Développements cliniques actuels à Nottingham

On a enregistré l'électrocardiogramme fœtal chez 155 femmes au cours du travail, à l'aide d'une électrode sur le scalp fœtal et d'une technique de valorisation avec moyennage par micro-ordinateur. On a diagnostiqué par analyse du sang fœtal prélevé au scalp l'hypoxie foetale, l'acidose et le stress et après l'accouchement par l'analyse complète des gaz du sang sur la veine et l'artère ombilicales. On a également mesuré sur le sang veineux ombilical les taux de lactates, d'adrénaline, de Nor-adrénaline, de potassium et d'hémoglobine.

Une onde P a été vue sur tous les tracés enregistrés. L'intervalle P-R est corrélé et avec l'activité du système nerveux autonome du fœtus et avec l'intervalle R-R fu fœtus en bonne santé. La corrélation entre les intervalles P-R et R-R change avec l'augmentation de l'acidose fœtale. Les modifications du complexe QRS sont variées et ne sont pas habituellement corrélées à l'état fœtal. Lorsque l'acidose fœtale augmente, des modifications du segment ST apparaissent. L'analyse de l'onde T, incomplète, n'a pas montré de corrélation évidente avec l'état fœtal.

Mots-clés: Acidose fœtale, électrocardiogramme, surveillance fœtale.

Dr. Henry G. Murray
Department of Obstetrics and Gynaecology
University Hospital
Queen's Medical Centre
Nottingham, NG7 2UH, U.K.